International Journal of Innovation Engineering and Science Research
(ISSN: 2581-4591)
www.ijiesr.com

# Bond Performance of Fiber Reinforced Concrete Exposed to Elevated Temperatures

**Sayed hussien Sayed hassanien**
*Housing and Building National Research Center, Cairo, Egypt;*

## ABSTRACT

In structural concrete design, adequate bond between the reinforcing steel and concrete is essential, especially when the reinforced concrete structure is exposed to accidental fire causing elevated temperatures. In this paper, the effect of fiber types and elevated temperatures on compressive strength and the bond characteristics of fiber reinforced concrete (FRC) are discussed and presented. Two types of steel fibers, corrugated and end-hooked, and two types of polypropylene fibers, ordinary and structural, were used. The experimental work includes eight mixes. A plain concrete mix, without fiber, was used as a control mix. Three mixes contained corrugated steel fibers with a various volumetric ratios of 1% , 1.5% and 2% while three mixes contained end-hooked steel fibers with a various volumetric ratios of 1% , 1.5% and 2%. The last two mixes contain a mixture of 1 % end-hooked steel fibers with one type of polypropylene fiber. specimens were produced and exposed to elevated temperatures at 300$^{o}$ and 600 $^{o}$C for 2 hours. Pull- out tests on cylinders (150*300 mm) and axial compression tests on cubes (150*150*150 mm) were carried out to evaluate the bond performance between 16-mm reinforcing steel rebars and fibrous concrete. The obtained results showed slight reduction in residual compressive and steel–concrete bond after exposure to 300 $^{o}$C temperatures for 2 hrs. On the other hand, a severe reduction in residual compressive and steel–concrete bond after exposure to 600 $^{o}$C temperature for 2 hrs was observed. Using fibers minimized the damage in steel–concrete bond under elevated temperature. Hooked steel fibers achieved the highest bond resistance against elevated temperatures followed, in sequence, by those prepared with structural polypropylene fiber .

***Keywords—*** *Elevated temperature, steel fiber, polypropylene fiber, , pull- out, bond strength*

## I. INTRODUCTION

The mechanical response of reinforced concrete (RC) structures (crack width, crack spacing, deflection, tension stiffening) is highly dependent on the efficiency of the bond stress transfer evenly distributed all along the rough contact surface between the reinforcing bar (rebar) and the surrounding concrete. According to the state of the art report [1], the description of the rebar-concrete bond is essentially based on an empirical approach. As a consequence, exposure to high temperatures may cause considerable variations in the physical and mechanical properties with irreversible loss of strength and stiffness [2,3].Concrete is commonly considered to have good fire resistance but chemical and physical reactions occur at elevated temperatures [2,4].

A fresh concrete that is not correctly placed and does not reach adequate hydration, contains free water, when subjected to elevated temperature; this water evaporates at 100$^{o}$C, causing fragmentation. In addition, this situation accelerates the evaporation of the bound water at 300$^{o}$ C in the hydrated elements. Thus, a rapid degradation of the concrete strength causes the temperature increase in reinforcement bars. On the other hand, calcium hydroxide, which is an important cement component, shrinks by 33% by losing water and transforms into quicklime at 530$^{o}$ C. During the fire, the water that is squeezed into the structure causes the quicklime changes, resulting in a volume expansion of 44%, and this sudden volume conversion causes cracking of the surrounding concrete [5]. It was also reported that the loss in bond strength could reach as high as 60% when RC is subjected to temperature exceeds excess of 500°C [6]. It was also concluded that, the specimens exposed to 800°C suffer a loss of the ultimate bond strength of 73.6% while the specimens exposed to 600°C suffer a loss of the ultimate bond strength of 67.8% compared with the specimens exposed to ambient temperature [7].

Pull-out test is frequently used to determine the bond between steel reinforcing bars and the surrounding concrete [8,9]. Previous experience showed that exposure of concrete to temperatures in excess of 400o C would have detrimental impact on its strength and integrity [10]. The loss in strength and/or spalling of concrete at high temperature was attributed to three major factors, namely vapor pressure of capillary and gel water, decomposition of cement hydration products, and possible collapse of filling aggregate [11]. It was reported that the loss in bond strength could reach as high as 60% when RC is subjected to temperatures in excess of 500$^{o}$ C [12,13].

Concretes with steel fibers (SF), polypropylene fibers (PPF) and polyvinyl alcohol fibers (PVA) showed good behaviors in fire in the controlling of the spalling [14,15]. In case of fire the PPF and PVA fibers melts around 170 and 230oC, respectively, and will create a network of micro-channels in the concrete which served as a way for the release of water vapor to the outside. Accordingly this will avoid the brittle type of failure in which explosive and the concrete becomes separated from the reinforcing bars.

The concrete specimens without additions suffer heavy loss of the mechanical properties by action of fire to reach a temperature of 650°C, leading to a loss of 73% of this capacity, but a considerable improvement of this loss of capacity by adding short (PP) fibers of 40% took place [16]. From the 200°C, (PP) fibers begin to deteriorate with mass loss. The temperature starting the destruction of the fibers are moved to a temperature of 350°C and the total destruction, 95%, to the temperature of 500°C [16].

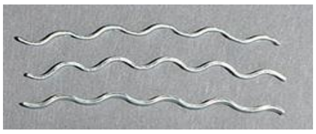
Compressive concrete strength has the most important role in RC structural members subjected to elevated temperature. According to the previous test results, it can be observed that a decrease of the concrete compressive strength with the elevated temperatures. Since the cement and aggregate forming the concrete, contain silica and limestone, it is expected that strength loss depends on various parameters. Particularly the quartz in silica-based coarse / fine aggregates, is subjected to polymorphic change at 570 °C temperature. This transformation causes volume increase and damage in concrete. Besides, in dolomitic aggregates, carbonate transforms into CaO or MgO at 800–900 °C. As temperature increases, limestone or dolomite expands; decomposition of CO2 and formation of CaO or MgO initiate shrinkage. Those volume changes also cause damage in concrete. According to the previous research results, 45% of the concrete compressive strength at 600 °C is preserved, but concrete residual strength is only 18% at 800°C.Other researchers reported that most considerable reduction of compressive strength took place between 400 °C and 800 °C in all cases within different temperature range. The residual compressive strength values at the maximum temperature of 800 °C were between 20 % to 30 % of the strength at 20 °C for concrete with (PP) fibers. [5,17]

## II. MATERIALS PROPERTIES

### Fibers

Four types of fibers were used in preparing different fibrous concrete mixtures namely: hooked steel fibers (HSF), Corrugated steel fibers CSF, structural polypropylene fibers (SPPF) and traditional polypropylene fibers (TPPF) . The properties of the used fibers are listed in Table 1.

( Table 1) Geometric and mechanical properties of fibers used in the present study

| Type | Geometrical configuration | Specific gravity (gm/cm3) | Fibers diameter (mm) | Fibers length (mm) | Aspect ratio |
|---|---|---|---|---|---|
| Hocked steel fibers ( HSF ) |  | 7.8 | 0.5 | 25 | 50 |
| Corrugated steel fibers (CSF) |  | 7.8 | 0.5 | 25 | 50 |
| Structural polypropylene fibers ( SPPF ) |  | 0.91 | 0.50 | 50 | 100 |
| Traditional polypropylene fibers ( TPPF ) |  | 0.91 | ------ | ----- | ------ |

**<u>Reinforcing steel</u>**

A ribbed steel rebars B500C-R, with 16 mm in nominal diameter, and complying with ESS 262-2015, were used [18].

**<u>Aggregate</u>**

Local sand from natural sources, crushed dolomite size (10 and 20) mm complying with Egyptian standard specification ESS No. 1109- 2001 [19]. were used

**<u>Cement</u>**

CEMI 42.5N, cement complying with ESS 4756- 2013 [20] was used.

**<u>Concrete Mix proportions and production</u>**

The consistency of concrete mix was measured by slump tests, as a comparison test, and ranged from 80 to 120 mm. The content of cement, water, aggregate, fibres and super plasticizer (Sp) required to produce one cubic meter of concrete are given in Table (2)

Table (2) : Concrete compositions per one m$^3$

| Mix | Cement (kg) | Fine Aggregate (kg) | Crushed dolomite S1 (kg) | Crushed dolomite S2 (kg) | Water (kg) | Add. | Fibers | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Sp (Lit) | *HSF (Kg) | **CSF (Kg) | ***T.PP (gm) | ****S.PP (kg) |
| M - C | 350 | 700 | 595 | 595 | 160 | 7 | ---- | ---- | ---- | ---- |
| M - CSF1 | 350 | 700 | 595 | 595 | 160 | 7.25 | 78 | ---- | ---- | ---- |
| M- HSF1 | 350 | 700 | 595 | 595 | 160 | 7.25 | ---- | 78 | ---- | ---- |
| M - CSF2 | 350 | 700 | 595 | 595 | 160 | 7.5 | 117 | ---- | ---- | ---- |
| M - HSF2 | 350 | 700 | 595 | 595 | 160 | 7.5 | ---- | 117 | ---- | ---- |
| M - CSF3 | 350 | 700 | 595 | 595 | 160 | 7.8 | 156 | ---- | ---- | ---- |
| M - HSF3 | 350 | 700 | 595 | 595 | 160 | 7.8 | ---- | 156 | ---- | ---- |
| M - HPF1 | 350 | 700 | 595 | 595 | 160 | 7.25 | | 78 | 900 | ---- |
| M - HPF2 | 350 | 700 | 595 | 595 | 160 | 7.25 | | 78 | ---- | 2.5 |

* end hocked steel fibers ** corrigated steel fibers

*** Traditional polypropylene fibers **** Structural polypropylene fibers

The experimental program was designed to measure the bond properties of steel reinforcing bars embedded in steel FRC and a mixture of steel FRC and polypropylene fibers (PPF). One concrete mix was not provided with any steel fibres so as to remain as a plain concrete and serve as the control concrete mix. Three mixes contained corrugated steel fibers with a various volumetric ratios of 1% , 1.5% and 2% while three mixes contained end-hooked steel fibers with a various volumetric ratios of 1% , 1.5% and 2%. The last two mixes contain a mixture of 1 % end-hooked steel fibers with one type of polypropylene fibers.

A two-steps mixing method was used at first the mortar portion, i.e (cement,sand,and water) with no coarse aggregate and no fibres was mixed in a high mixer and then mixing the mortar portion with coarse aggregate, fibres and SP in a concrete mixer was conducted. After mixing, a sample was taken for slump-flow test. If the measured slump had not reached the required value, a bit more SP was added and the concrete mix was remixed for another 1 min. After achieving the required slump, three 150mm diameter×300mm height cylinder specimens were cast for compression test and three 150 mm cube specimens each with a rebar embedded inside were cast for test. All the specimens were remoulded after casting and then cured in a lime-saturated water tank for 28 days, at a temperature of 27 ± 3 °C.

## III. RESEARCH PROGRAM

The experimental test program was designed to achieve the research objectives of the study. Bond behaviour between concrete and reinforcing bars was studied after exposure to elevated temperatures at 300 and 600°C for 2 hours. Nine different concrete mixes with different fiber percentages were used as shown in table (1). Eighty one pull-out cylinder specimens (Ø150 mm, 300 mm) were prepared, then, reinforced steel bar of 16mm was embeded in the middle of each cylinder for 200mm, see figure (1-a). The reinforced steel bar's embedded length was controled by a horizontal steel bar above the cylinders, as shown in figure (1-a). After removing the specimens from the formwork, they were stored in water for seven days then kept at laboratory conditions until testing. Finally, the specimens were tested at room temperature see (1-b) . Standard cubes were cast for each mix, cured in the same condition as the pullout cylinders specimens, then tested to determine the compressive strength.

| | |
|---|---|
|  |  |
| Figure (1-a) : Controlling the bar's embedded length | Figure (1-b) : Pull out Test |
| Figure (1): Preparing, casting and testing the specimens | |

## IV. HEATING PROCEDURE

All specimens exposed to heat, the outer part of the tested rebar was not covered in order to simulate what may happen in real life applications. The specimens were heated in a gas furnace up to 300 $^{\circ}$C and 600 $^{\circ}$C. Each temperature was maintained for 2 hours before removing the specimens from the furnace and then cooled at room temperature. The gas furnace, specimens before and after exposure to elevated temprature are shown in Figure (2)

| | | |
|---|---|---|
|  |  |  |
| The gas furnace | Specimens in the furnace | Specimens after exposure to elevated temperature |

Figure (2): The gas furnace, specimens before and after exposure to elevated temprature

## V. TEST RESULTS AND DISCUSSION

### Failure Mode

Failure modes due to the pullout force changed according to the type and dosage of each fiber used in concrete specimens.The control specimens failed in splitting (the cylinder splitted into two halves), as shown in figure (3a). To avoid this type of failure mode, two types of steel fibers with different dosage were used, they obviously affected the mode of failure of tested specimens as shown in figure (3b), the tested cylinders didn't split into two halves and cracks propagated up to failure. Those cracks became narrower when 1% steel fibers were added to 1% (PP) fiber (hybird mixes), see figure (3c). For all fiber concrete mixes, bond failure partly occurs on the surface of the bar and partly in the concrete by peeling the cortical layer of the bar.

<table>
<tr>
<td rowspan="2"></td>
<td>


</td>
<td rowspan="2"></td>
</tr>
<tr>
<td>


</td>
</tr>
<tr>
<td>Figure (3a): failure of control mix</td>
<td>Figure (3b): failure of (SF) fiber mixes</td>
<td>Figure (3b): failure of hybird fiber mixes</td>
</tr>
</table>

Figure (3): Failure Modes of pullout test specimens of different mixes

## VI. Compressive concrete Strength

The compressive strength of concrete cubes were determined before and after heat-treatment .The test value was taken as the average of three cube specimens.

The reduction of compressive strength for corrigated steel fiber mixes ( M - CSF1, 2 , 3) after exposure to 300 °C for 2 hrs compared with the same mixes at room temperature were 5 %, 5 % and 6 % respectivily. But after exposure to 600 °C for 2 hrs the reduction of compressive strength was 55%,53% and 53% respectivily compared with the same mixes at room temperature as shown in figure (4a).

For the mixes ( M - HSF1, 2 , 3) recorded an avarege reduction of 7% after exposure to 300 °C for 2 hrs and 55 % after exposure to 600 °C for 2 hrs as shown in figure (4b).

The mixes which provided with steel fibers achieved an improvement of compresive strength with 63% if compared to the compresive strength of control Mix (M-C) at the same exposure conditions.

For the mixes which contain a mixture of steel and structural Polypropylene fibers (M - HPF1) recorded a reduction of 10 % after exposure to 300 °C for 2 hrs and 54 % after exposure to 600 °C for 2 hrs, a shown in figure (3c). On the otherhand mix (M - HPF2) recorded a reduction of 6 % after exposure to 300 °C for 2 hrs and 51 % after exposure to 600 °C for 2 hrs as shown in figure (4c).
So, clarified that steel fiber has a significant effect on concrete compressive strength subjected to elevated tempreature, such behavior may be related to: -

{a} the partial loss in bond between fibers and surrounding matrix due to the difference in their expansion coefficients at high temperatures.
{b} the higher sensitivity of fibrous concrete mixtures to high temperatures as compared to plain concrete, due to the greater strength of the fibrous concrete mixture at room temperature. Heating to 600° C generated extensive cracking and sometimes spalling in the cubic specimens, which was reduced by the use of fibers. The results showed an avarege reduction in compressive strength proportional with increasing the elevated temperature

Table (3) : Compressive strengths results before and after exposure to elevated tempertaure

| Mixes | Room Temp. | | 300 °C | | 600° C | |
|---|---|---|---|---|---|---|
| | Compressive strength (kg\cm2) | Residual Strength (%) | Compressive strength (kg\cm2) | Residual Strength (%) | Compressive strength (kg\cm2) | Residual Strength (%) |
| M - C | 376 | (100 %) | 319 | (85 %) | 140 | (37 %) |
| M - CSF1 | 390 | (100 %) | 370 | (95 %) | 175 | (45 %) |
| M - HSF1 | 392 | (100 %) | 368 | (93 %) | 186 | (47 %) |
| M - CSF2 | 401 | (100 %) | 381 | (95%) | 188 | (47%) |
| M - HSF2 | 395 | (100 %) | 363 | (92 %) | 165 | (41 %) |
| M - CSF3 | 412 | (100 %) | 386 | (94 %) | 195 | (47 %) |
| M - HSF3 | 400 | (100 %) | 376 | (94 %) | 184 | (46 %) |
| M - HPF1 | 415 | (100 %) | 372 | (90 %) | 192 | (46 %) |
| M - HPF2 | 401 | (100 %) | 377 | (94 %) | 198 | (49 %) |

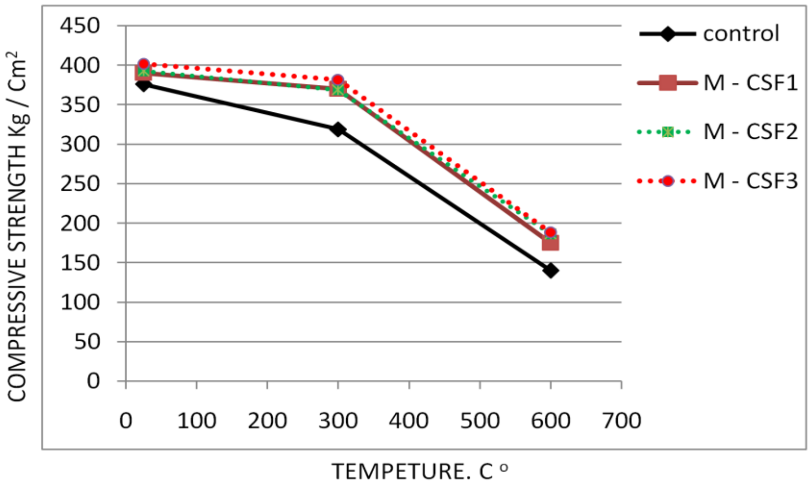



Figure (4a): Compressive strength of ( CSF) fiber mixes at different temperatures

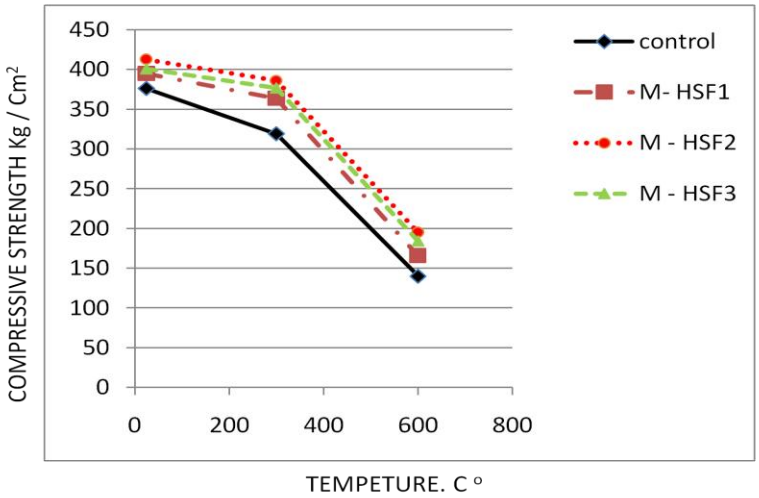



Figure (4b): Compressive strengths of ( HSF) fibers mixes at different temperatures

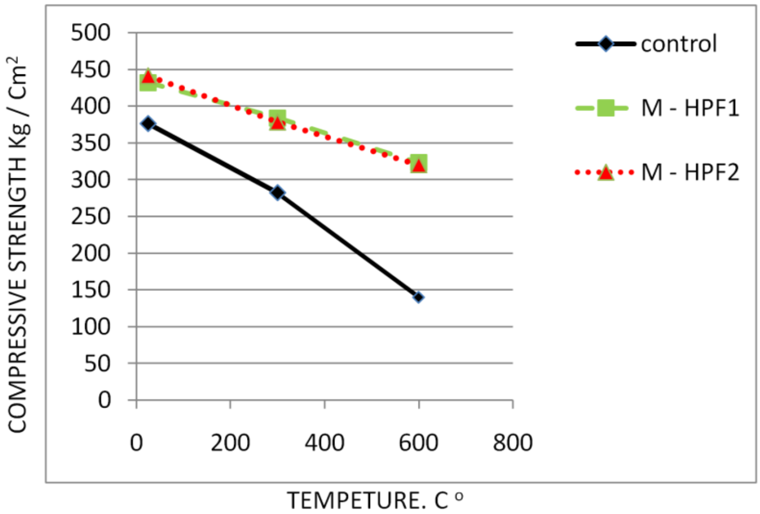



Figure (4b): Compressive strengths of ( HPF) fiber mixes (hybird mixes) at different temperatures

**Bond Strength**

Bond strength between reinfoced steel bars and concrete was evaluated by pull-out test after exposure to elevated temperatures (from room temperature up to ( 600 ºC) according to ASTM C234-91[21]. The results state that the relative residual bond strength for all tested specimnes decreased significantly with increasing the tempreture . table (4) summarize the bond strength results.

**At room tempreture**

For mixes ( M - CSF1, 2 , 3) the bond strength incresed by the average value of 43 % compared with the control mix (M-C) . For mixes ( M - HSF1, 2 , 3) the bond strength incresed by the average value of 47 %. Mix (M - HPF1) and mix ( M - HPF2 ) increase in the bond strength by 74 % and 62 % respectively. Mix ( M - CSF3 ) with volumetric ratio of 2 % gives the reasonable improvement in bond strength, and so it can be conclude that the percentage of fibers in the range of 2 % is considered an appropriate proportion to increase the bond strength. on the other hand, mix (M - HPF1) gives the best improvement in bond strength as shown in figure (5).

**At ( 300 ºC) tempreture**

The average residual bond strength for the control mix (M-C) recorded the worst value of 25 %, while the average residual bond strength for mixes ( M - CSF1,2,3) was 37 %. For mixes ( M - HSF1,2,3) The average residual bond strength was 40 %. On the other hand the average residual bond strength for mixes (M - HPF1) and ( M - HPF2 ) was 46 % and 49 %, respectively. it can be seen that mix (M - HPF2) gives the best improvement in residual bond strength as shown in figure (5).

**At ( 600 ºC) tempreture**

The average residual bond strength for the control mix (M-C) recorded recorded the worst value of 10 %, while the average residual bond strength for mixes ( M - CSF1,2,3) was 21 % . For mixes ( M - HSF1,2,3) the average residual bond strength was 24 %. On the other hand the average residual bond strength for mixes (M - HPF1) and ( M - HPF2 ) was 26 % and 27 %, respectively. it is obvious that, Mix (M - HPF2) gives the best improvement in residual bond strength as shown in figure (5).

From the previous results it can be seen that the mixes ( M - CSF1,2,3) and ( M - HSF1,2,3) achieve an improvement in the residual bond strength of 48% and 60% ,respectively at 300$^o$C, and 110% and 140% ,respectively at 600$^o$C compared with the control Mix (M-C) at the same exposure conditions because of the use of fibers reduced crack sizes on the surfaces of modified pullout specimens and limited or prevented crack propagation throughout the modified pullout sides.

The mixes (M - HPF1) and ( M - HPF2 ) achieve an extra improvement in the residual bond strength of 160% and 170% ,respectively at 600$^o$C compared with the control Mix (M-C) at the same exposure because of the escape channels formed by melting of the polypropylene fibres, impart limited improvement in bond resistance against heating because of the reduction in both splitting and compressive strengths as a result of the increase in the overall porosity.

Table (4) : bond strength results before and after exposure to elevated tempertaure

| Mixes | Room Temp. | | 300 $^o$ C | | 600$^o$ C | |
|---|---|---|---|---|---|---|
| | Bond strength (kg\cm$^2$) | Residual Strength (%) | Bond strength (kg\cm$^2$) | Residual Strength (%) | Bond strength (kg\cm$^2$) | Residual Strength (%) |
| M - C | 74.00 | (100 %) | 18.50 | (25 %) | 7.50 | (10 %) |
| M - CSF1 | 91.00 | (100 %) | 29.00 | (32 %) | 17.00 | (19 %) |
| M - HSF1 | 96.00 | (100 %) | 34.00 | (35 %) | 20.00 | (21 %) |
| M - CSF2 | 103.00 | (100 %) | 37.00 | (36%) | 22.60 | (22%) |
| M - HSF2 | 110.00 | (100 %) | 44.00 | (40 %) | 27.50 | (25 %) |
| M - CSF3 | 125.00 | (100 %) | 52.50 | (42 %) | 26.00 | (21 %) |
| M - HSF3 | 120.00 | (100 %) | 54.00 | (45 %) | 29.00 | (24 %) |
| M - HPF1 | 129.00 | (100 %) | 59.00 | (46 %) | 33.00 | (26 %) |
| M - HPF2 | 122.00 | (100 %) | 60.00 | (49 %) | 33.00 | (27 %) |

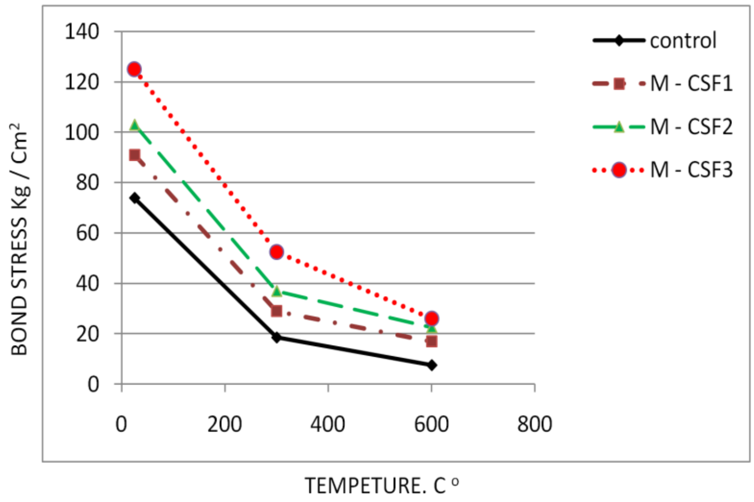



Figure (5a): Bond strengths of ( CSF) fiber mixes at different temperatures

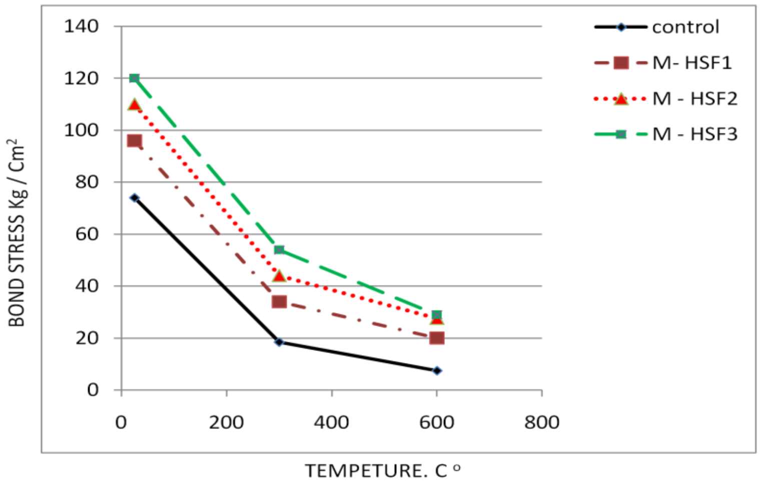



Figure (5b): Bond strengths of ( HSF) fiber mixes at different temperatures

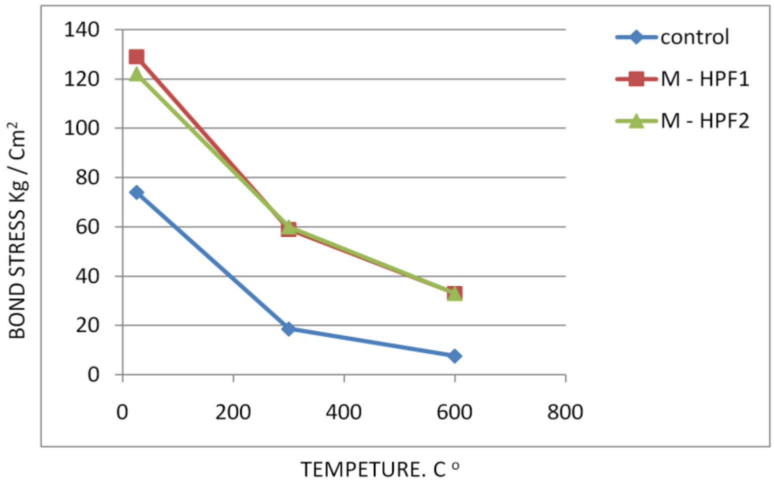



Figure (5c): Bond strengths of ( HPF) fiber mixes (hybird mixes) at different temperatures

## Conclusions

The following main conclusions can be drawn from the experimental results experimental results:

1. Using corrugated steel fibers (CSF), hocked steel fibers (HSF) and hybrid fibers slightly improved the concrete compressive strength by 6.6,5.2 and 8.50 %, respectively. While significantly enhance the bond strength between the reinforced bars and concrete by 43 , 47 and 68 %, respectively.
2. Exposure to 300 ºC for 2 hrs. didn't affect the average of both compressive and bond strength significantly, as the average strength loss didn't exceed 16% of those in room temperature for all mixes,
3. Exposure to high temperature of 600 ºC for 2 hrs. significantly reduces the compressive strength of no fiber concrete by 63% and that reduction improved by using corrugated steel fibers (CSF), hocked steel fibers (HSF) and hybrid fibers to reach 53 , 55 and 52.5 %, respectively of the original compressive strength for specimens in room temperature.
4. Exposure to high temperature of 600 ºC for 2 hrs. significantly reduces the ultimate bond strength of no fiber concrete by 90% and that reduction enhanced by using corrugated steel fibers (CSF), hocked steel fibers (HSF) and hybrid fibers to become 79, 74 and 73%, respectively of the original bond strength for specimens in room temperature.
5. An improvement of bond strength compared to the control specimen after exposure to 600 ºC up to 54 % occured when using both types of (SF) fiber, while the greatest enhancement was recorded62 % in hybird mixes containing both (PP) and hooked steel fiber together .
6. Using of 1% steel fibers with 1% PP fibers recorded the highest bond strength among all tested specimens whether subjected to elevated temperature or not.
7. The control specimens failed in splitting (the cylinder splitted into two halves), but using using the two types of steel fiber ,separetely, obviously affected the mode of failure of tested specimens as the tested cylinders didn't split into two halves and cracks propagated up to failure. Those cracks became narrower when hybird fibers were used.
8. For all fiber concrete mixes, bond failure partly occurs on the surface of the bar and partly in the concrete by peeling the cortical layer of the bar.

## REFERENCES


[1.] Bond of Reinforcement in Concrete: State-of-Art Report, Bulletin 10. fib (CEB-FIP), 2000.

[2.] L. Biolzi, S. Cattaneo, and G. Rosati, "Evaluating Residual Properties of Thermally Damaged Concrete," Cement & Concrete Composites, 30, 907– 916, 2008.

[3.] C. Castillo, and A. J. Durrani, "Effect of Transient High Temperature on High Strength Concrete," ACI Materials Journal, 87(1), 47–53, 1990

[4.] L. T. Phan, and N. J. Carino, "Review of Mechanical Properties of HSC at Elevated Temperature," Journal of Materials in Civil Engineering, 10(1), 58–64, 1998.

[5.] F. M Özkal et al, "Mechanical Properties and Bond Strength Degradation of GFRP and Steel Rebars at Elevated Temperatures", Construction and Building Materials 184 45–57, 2018

[6.] H.M. Selim et al, " Bond Characteristics of ASTM A1035 Steel Reinforcing Bars", ACI structural journal, July/ August, 530:539. 2009

[7.] N. G.,et al, ″ Evaluation of Bond Strength Between Steel Rebars and Concrete for Heat Damaged and Repaired Beam-End Specimens", Cement and Concrete Research journal. 32 1009–1018. 2002, [8.] M. Haskett, D. J. Oehlers, and M. S. M. Ali, "Local and Global Bond Characteristics of Steel Reinforcing Bars," Engineering Structures, 30, 376–383, 2008.

[9.] R. H. Haddad, R. J. Al-Saleh, and N.M. Al-Akhras, "Effect of Elevated Temperature on Bond Between Steel Reinforcement and Fiber Reinforced Concrete," Fire Safety Journal, 43 334–343, 2008.

[10.] Annual Book of ASTM Standards, Concrete, American Society for Testing Materials, 1993.

[11.] RILEM, Bond test for reinforcement steel: 2-pull-out test, Recommendation RC6, CEB News 73, 1983.

[12.] V. Kodur, R. McGrath, Fire Endurance of High Strength Concrete Columns, Fire Technol. 89 (2003) 73–87.

[13.] P. Morely, R. Royles, Response of The Bond in Reinforcing Concrete to High Temperatures, Mag. Concr. Res. 35 (123) 67–74. 1983

[14.] J. P. C. Rodrigues, L. Laim, and A. M. Correia, "Behaviour of Fiber Reinforced Concrete Columns in Fire," Composite Structures, 92, 1263– 1268, 2010.

[15.] A. Lau, and M. Anson, "Effect of High Temperatures on High Performance Steel Fiber Reinforced Concrete," Cement and Concrete Research, 36, 1698–1707, 2006.

[16.] E.P.S de Linares, University of Jaén, Spain GEA 21, Spain, " The Fire Resistance of Concrete with Polypropylene Fibers", MATEC Web of Conferences 6, 02005 (2013).

[17.] Éva Lublóy and Balázs L. György "Temperatures Effects on Bond Between Concrete and Reinforced Steel", Journal of Faculty of Civil Engineering, 26 (2014).

[18.] ESS 262-2015, "reinforced steel in concrete" .

[19.] ESS No. 1109- 2001," Aggregate for Concrete" .

[20.] ESS No. 4756- 2013, "Cement, Part One; Composition, Specifications and Conformity Criteria for common Cements".

[21.] ASTM C234-91a, Standard Test Method for Comparing Concretes on the Basis of the Bond Developed with Reinforcing Steel